Indian J. Phys. **74B** (2), 163–165 (2000)

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I J P B
— an international journal

Radiation characteristics of the ferrite based microstrip planar phased array antenna

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Received 15 March 1999, accepted 9 September 1999

Abstract : We present an analytical study of a 2 × 2 element planar phased array antenna comprising four identical microstrip circular patches and built up on a typical ferrite substrate in plasma medium. The far zone field expressions are obtained using well established hydrodynamic theory and vector wave function technique The performance of field patterns show substantial improvement in the radiation capability in comparison to its dielectric counterpart antenna.

Keywords : Ferrite substrate, microstrip phased array antenna, radiation characteristics

PACS Nos. : 84.40.Ba, 52.40.Fd

Due to their light weight, flat profile, low manufacturing cost and compatibility with integrated circuits, microstrip antennas have become the right choice for communication. In the early years, dielectric based microstrip antennas were shought, but recently ferrite based microstrip antennas are becoming increasingly popular in many communication systems for aerospace vehicles, satellites and manportable applications [1–4], because of their wide versatility which can provide more symmetrical lobes with lower side lobes. It has been established earlier that the free space radiation characteristics of the microstrip antennas differ significantly from their counterpart plasma radiation characteristics. This is due to the generation of the electroacoustic waves in addition to the electromagnetic waves [5,6]. In the present endeavour, we have made an analysis to study the radiation characteristics of a 2 × 2 element planar phased array microstrip antenna on a typical ferrite substrate both in plasma as well as in free space media. The far-zone field patterns (electromagnatic and electroacoustic) and their derived parameters for such a system are reported in the two different planes (E-plane and H-plane).

The configuration and coordinate system of a planar array antenna taking four microstrip patches are shown in Figure 1. The four identical circular patches of radius a each of them is kept on a substrate of thickness h in a

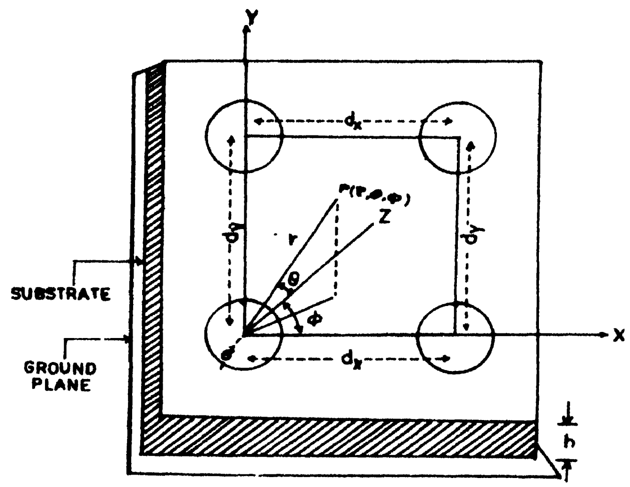

Figure 1. Configuration and coordinate system of 2 × 2 element plannar phased array antenna.

planar arrangement. The array elements which are positioned along x-axis are separated by a distance d_x and those along y-axis are separated by a distance d_y. Each patch can be excited by a microstrip transmission line connected to the edge or by a coaxial line from the back at the plane

$\phi = 0$. Among the various modes that may be excited in such resonators, T_{nm} Mode with respect to z-axis is chosen.

Following our earlier work [7] and the theory of ferrites [8], the total far-zone fields are

$$E_{\theta t} = j^n \xi \cos n\phi J_n'(\beta_e a \sin\theta), \quad (1)$$

$$E_{\phi t} = j^n \xi \sin n\phi \cos \frac{J_n(\beta_e a \sin\theta)}{\beta_e a \sin\theta}, \quad (2)$$

$$E_{pt} = (-j)^{n+2} \chi \sin n\phi J_n(\beta_p a \sin\theta), \quad (3)$$

with $\xi = V_0 a \beta_e \dfrac{\exp(-j\beta_e r)}{2r}$

$$\times \cos\{0.5(\beta_e d_x \sin\theta\cos\phi + \beta_x)\}$$

$$\times \cos\{0.5(\beta_e d_y \sin\theta\sin\phi + \beta_y)\}$$

and $\chi = \dfrac{60\pi(1-A^2)}{A}\left(\dfrac{c}{v}\right) K_1^2 n J_n(K_1 a) \dfrac{\exp(-j\beta_p r)}{r}$

$$\times \frac{\sin(\beta_p h \cos\theta)}{\beta_p h \cos\theta} \cos\{0.5(\beta_p d_x \sin\theta\cos\phi + \beta_x)\}$$

$$\times \cos\{0.5(\beta_p d_y \sin\theta\sin\phi + \beta_y)\},$$

where

- $E_{\theta t}, E_{\phi t}$ Components of total electric field vector for *EM* mode,
- E_{pt} Total electric field vector for plasma mode,
- J_n n-th order Bessel's function of first kind,
- J_n' Derivative of Bessel's function of first kind,
- V_0 Feed point voltage,
- r Magnitude of position vector of point P,
- v r.m.s. thermal velocity of electron in plasma given by 3 KT/m, K being the Boltzman's constant and m being the mass of electron,
- β_e : The EM mode propagation constant given by $\frac{2\pi}{\lambda_0}\sqrt{\mu_{eff}}A$, μ_{eff} being the effective permeability of the substrate,
- A : The plasma parameter given by $\left(1-\omega_0^2/\omega_p^2\right)^{1/2}$,
- K_1 : $(\omega_0 \mu_0 \varepsilon_0 \varepsilon_{eff} \mu_{eff})^{1/2}$, ε_{eff} being the effective permitivity of the substrate given as [8].

$$\frac{\quad}{2.} \cdot \frac{-p}{2}\left(1 + 10\frac{h}{a}\right)^{-1/2} \quad (4)$$

with $\varepsilon_p = A^2$

In the eqs. (1–3), the array factor $\cos\{0.5(\beta d_x \sin\theta\cos\phi + \beta_x)\} \cos\{0.5(\beta d_y \sin\theta\sin\phi + \beta_y)\}$ (subscripts e or p as for EM mode or p-mode has been taken in the normalized form.

The total field patterns $R(\theta,\phi)$ are obtained from the relation

$$R(\theta,\phi) = |E_{\theta t}|^2 + |E_{\phi t}|^2. \quad (5)$$

The values of $R(\theta,\phi)$ for microstrip planar phased array antenna, which is built up on a typical ferrite substrate $Ni_{1.062}Co_{0.02}Fe_{1.984}O_4$ with $\mu_{eff} = 14.78$ and $\varepsilon_r = 14.78$ are obtained and plotted in Figure 2 for two different planes (*i.e.* $\phi = 0$ and $\phi = \pi/2$ plane) for $A = 0.5$ *i.e.* in plasma and $A = 1.0$ *i.e.* in free space. The input parameters

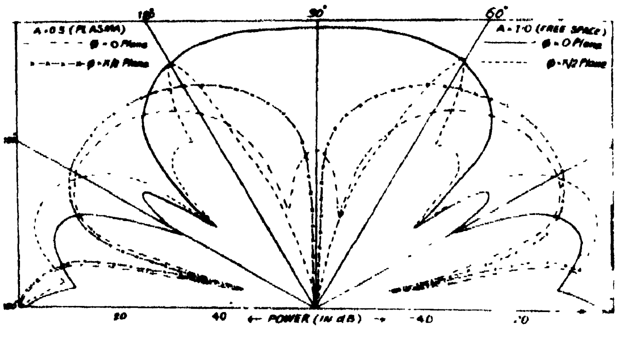

Figure 2. Variation of $R(\theta,\phi)$ for $A = 1.0$ (free space and $A = 0.5$ (Plasma) for 2 × 2 element planar phased array antenna in $\phi = 0$ and $\phi = \pi/2$ plane

for the present array system are taken same as reported earlier [7] in order to search the better results for the ferrite substrate.

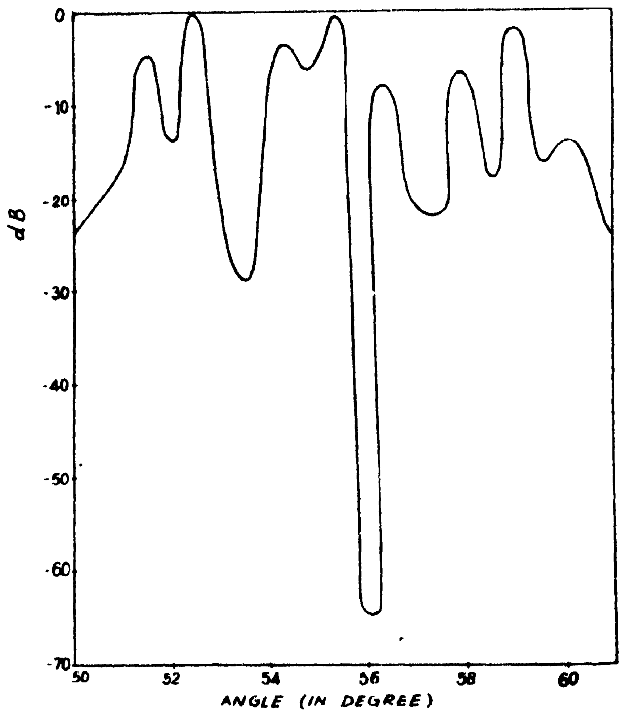

Figure 3. Plasma mode field pattern $|E_{pt}|^2$. For $A = 0.5$ for 2 × 2 element planar phased array antenna.

Table 1. Comparison of the main features of two array antennas : (i) Ferrite based, (ii) Dielectric based [7].

S N.	Array features	Array antennas			
		Ferrite based antenna		Dielectric based antena	
		$A = 1.0$ (Free space)	$A = 0.5$ (Plasma)	$A = 1.0$ (Free space)	$A = 0.5$ (Plasma)
(A)	Electromagnagic mode				
1.	Direction of main lobe				
	(a) $\phi = 0$ plane	65°	0°	0°	0°
	(b) $\phi = \pi/2$ plane	20°	0°	0°	0°
2	H P B W (degrees)				
	(a) $\phi = 0$ plane	24	10	20	44
	(b) $\phi = \pi/2$ plane	12	12	18	36
3	Maximum field Intensity				
	(a) $\phi = 0$ plane	0 1744	0 1251	0 1251	0 1251
	(b) $\phi = \pi/2$ plane	0 1307	0 1251	0 1251	0 1251
(B)	Plasma mode (total no of Lobes in 10° interval).	–	8	–	6

The electroacoustic (plasma) mode fields are computed for $A = 0.5$ in $\phi = \pi/2$ plane at 0.5 increments of θ in a small interval of 10°. Assuming that there is no lobe narrower than 0.5° the normalized values of the plasma mode field patterns are plotted between $\theta = 50°$ to $\theta = 60°$ in Figure 3.

From the analytical point of view, the direction of the main beam, half power beam width (HPBW) and the maximum field intensity for both the array antennas are presented in Table 1.

It is obvious that the radiation characteristics of the present array antenna system, significantly differ from its dielectric based counterpart antenna [7]. Figure 2, which illustrates the Em mode radiation field pattern of the antenna for free space ($A = 1.0$) and plasma ($A = 0.5$) in $\phi = 0$ and $\pi/2$ planes, justify that the field intensity redistributesconsiderably in plasma medium, as the shape of the field patterns has been modified to a great extent. The side lobe level of maxima which was too much in case of the dielectric based antenna [7] reduces considerably and exists in the appropriate limit, nevertheless former has less number of side lobes. In both the arrays, there is a symmetric change in all the four quadrants. The plasma mode field patterns possess (Figure 3) many lobes in 10° interval which is a common thing [7]. From Table 1, it is clear that the half power beam width (3 dB) is altered considerably for ferrite based array antenna in plasma medium. The HPBW of the nearby side lobe is enough ($\phi = 0$, $A = 0.5$), which may be useful for the several communication systems especially in case of false target indication. The present antenna study is also supposed to be helpful for the prospective antenna designers.

Acknowledgment

The author is thankful to the principals (Govt. Degree College, Lansdowne & Govt. P. G. College, Kashipur) for providing the necessary facilities and encouragement.

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